Coastal Engineering Technical Note

RIPRAP REVETMENT DESIGN

PURPOSE: To present a method and procedure for designing uniform-stone and graded-stone revetments for protection against wave attack.

GENERAL: Revetments are used to protect ocean, estuary, and lake shorelines from wave attack. Because of increased construction in many coastal areas, some additional revetments may be needed along higher valued exposed embankments. For many of these revetments quarrystone is a common building material because it is often locally available, relatively inexpensive, and does not require complex construction techniques. On projects with a high degree of public access, minimum stone size of between 400 and 500 lb may be required to prevent vandalism.

A sound approach to the design of a revetment structure for a particular site requires a careful study of existing structures in the area with similar wave exposure in order to evaluate the design in relation to the present condition. These data, along with presently available empirical formulae, are then used for design of the revetment. Since the wave attack on a revetment is directly related to the high and low tides as well as the design stillwater level (SWL), these must be determined in order to find which type of wave (nonbreaking, breaking, or broken) the revetment will encounter. In many cases no comparable structures exist in the proximity of the study area, or those of a similar revetment design may have completely different wave exposure and are thus of limited value for comparison. The following example illustrates a design procedure using presently available formulas for the design of a riprap revetment. For guidance on riprap channel protection, see ETL 1110-2-120 (Headquarters, Department of the Army 1971).

EXAMPLE: Design a riprap revetment to prevent the erosion of a bank in a coastal area with a 2.5-ft spring tide and a storm surge or wind setup effect of 1 ft. The toe of the revetment is to be located at the mean low water line. A total design depth of water at the toe of the structure d_s is 2.5 + 1 = 3.5 ft. The depth d_b that initiates wave breaking directly against the revetment may actually be at some distance seaward of the toe of the revetment (see Figure 1).

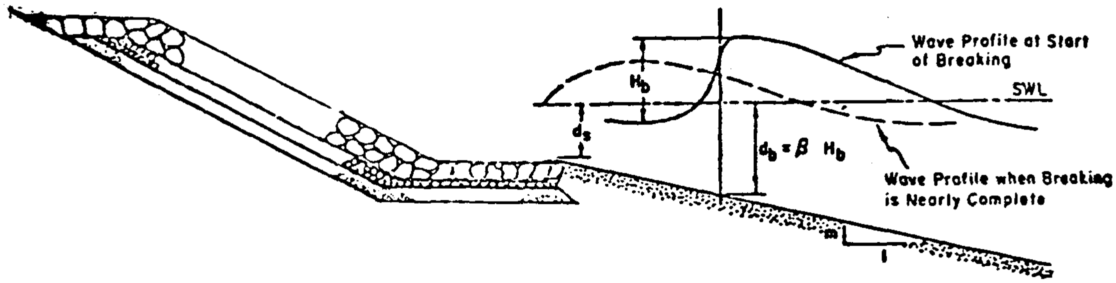

Figure 1. Definition of breaker geometry

The available data indicate that significant waves with heights and periods in excess of 8 ft and 10 sec are expected to occur at least once a month. Since these waves will break seaward of the structure, the design wave will be depth limited. The nearshore slope seaward of the structure is m = 0.050 (1:20). It is further assumed that the design wave for the stability of the quarrystone revetment is the maximum wave that breaks directly on the structure.

First, using Figure 7-4 of the Shore Protection Manual (SPM) (1984), determine the maximum wave that breaks on the structure with d_s = 3.5 ft, a nearshore slope m = 0.050 (1:20), and a range of wave periods from 4 to 10 sec.

T (sec)	$\frac{d_s}{gT^2}$	$\frac{H_b}{d_s}$	H_b (ft)	
4	0.0068	1.11	3.9	
6	0.0030	1.26	4.4	
8	0.0017	1.32	4.6	
10	0.0011	1.35	4.7	
12	0.00075	1.37	4.8	(check)

The check is to determine if underestimating of the wave period will significantly affect the breaker height.

For this particular example, the configuration of the bank determines the slope of the revetment to be 1:2. In order to select the top elevation of the revetment, the limit of wave runup should be determined by consulting Section II, Chapter 7, of the SPM and CETN III-2, "Runup on Composite Rough Slopes." The structural stability and the extent of wave runup on the slope depend on whether the armor stone on the revetment is graded riprap or a two-stone layer of uniform armor stone. In this example, both types of revetment armor will be structurally designed and compared.

The stable armor stone weight W is determined by Equation 7-116 (SPM 1984):

$$W = \frac{w_r \; H^3}{K_D(S_r - 1)^3 \cot\theta}$$

where

w_r = 165 lb/ft^3 (unit weight of armor unit)

H = 4.7 ft (design wave at revetment)

K_D = 2.0 (stability coefficient from Table 7-8, page 7-206 (SPM 1984), for breaking-wave condition and 2 random layers of rough angular quarrystone-use structure trunk)

$S_r = w_r/w_w$ = 165/64 = 2.58 (specific gravity of armor unit)

w_w = 64.0 lb/ft^3 (unit weight of water at the site)

$\cot\theta$ = 2 (slope 1:2) (angle of revetment slope)

Substituting in Equation 7-116:

$$W = \frac{165 \; (4.7)^3}{2.0 \; (2.58 - 1)^3 \; (2)} = 1.090 \text{ lb}$$

The range of armor stone weights for a cover layer of 2 quarrystones could vary from 0.75W to 1.25W (820 to 1,360 lb) with about 50 percent of the individual stones weighing more than W(1,090 lb).

The average thickness of the armor stone layer r is determined by Equation 7-121 (SPM 1984) as follows:

$$r = n \; k_\Delta \left(\frac{W}{w_r}\right)^{1/3}$$

where

n = 2 (layers of armor units)

k_Δ = 1.00 (layer coefficient Table 7-13 (SPM 1984))

w_r = 165 lb/ft^3

W = 1,090 lb

Substituting in the equation,

$$r = 2(1.00) \left(\frac{1{,}090}{165}\right)^{1/3} = 3.75 \text{ ft}$$

For the underlayer 1,090/10 = 109 lb 110 lb with a weight range of 80 to 140 lb with 50 percent heavier than 110 lb.

Equation 7-116 (SPM 1984) determines the weight of an armor unit of nearly uniform size. For a graded riprap armor stone, Equation 7-117 (SPM 1984) should be used as follows:

$$W_{50} = \frac{w_r H^3}{K_{RR} \left(S_r - 1 \right)^3 \cot\theta}$$

The symbols are the same as defined for Equation 7-116 except that W_{50} is the weight of median size of the stone. The maximum weight of graded rock is 4.0 W_{50}; the minimum is 0.125 W_{50}. K_{RR} is a stability coefficient for angular, graded riprap, similar to KD. Values of K_{RR} are shown in Table 7-8 (SPM 1984). These values allow for aboutu 5 percent damage.

Using Equation 7-117, let $K_{RR} = 2.2$:

$$W_{50} = \frac{165\ (4.7)^3}{2.2\ (2.58 - 1)^3\ (2)} = 990 \text{ lb}$$

Accordingly, the minimum weight W_{min} is 0.125 W_{50} or 120 lb and the maximum weight W_{max} is 4.0 W_{50} or 3,960 lb.

Comparison of the uniform stone to be graded stone is shown below:

Armor Units	Weights
Uniform stone	820 to 1,360 lb
	Minimum = 120 lb
Graded stone	Median = 990 lb
	Maximum = 3,960 lb

It can be shown that the uniform weight of stone could result in a less massive and more economical structure because of the wide range of armor stone required in the graded stone revetment design. Figures 2 and 3 summarize the uniform and graded stone revetment design. The underlayer should be designed in accordance with Chapter 7, Section III,7,g,(8), pages 7-239 and 7-240 of the SPM (1984). The filter design is in Section III,7,g,(9), pages 7-240, 7-241, and 7-242) of the SPM.

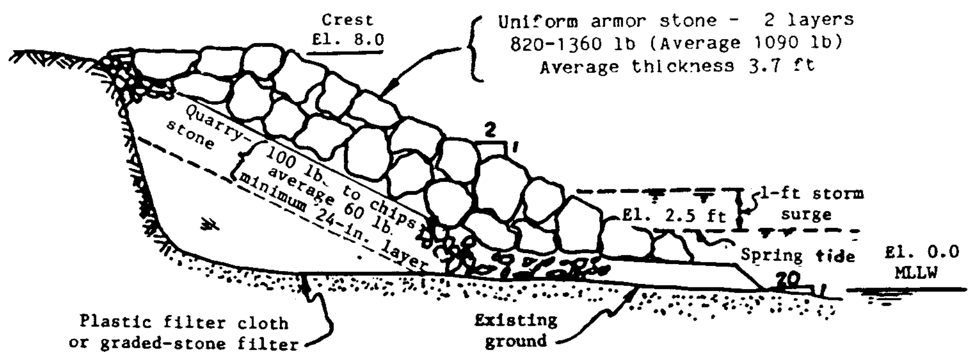

Figure 2. Uniform quarrystone revetment design

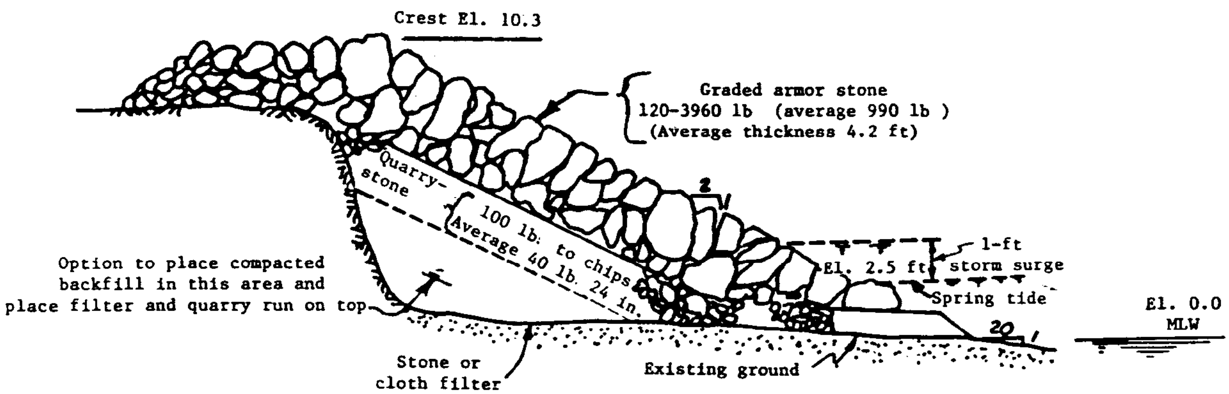

Figure 3. Graded quarrystone revetment design

For graded revetment it is suggested that the underlayer average weight be approximately 0.05 W_{50} or $W_{50}/20$ = 990/20 $\approx$50 lb (using the same underlayer design used for uniform quarrystone). The layer thickness should be no less than 2 times the average dimension of the W_{50} quarrystone (Table 7-12) (SPM 1984), 2 x 2.1 ft or 4.2 ft. A check should be made to determine if the maximum quarrystone weight ($\approx$4,000 lb) will fit into the 4.2 ft minimum layer thickness. Average dimension of 4,000 lb quarrystone is 3.3 ft (from Table 7-12) (SPM 1984). It is further recommended that the layer thickness for the graded quarrystone should be >1.25 times the dimension of W_{max} so as to accommodate the full range of gradation with adequate thickness for stone under the maximum weight armor (1.25 x 3.3 = 4.1 ft). If a contractor can obtain the graded quarrystones for about 80 percent of the cost for uniform quarrystones, which accounts for approximately one-half of the revetment cost,

and placement cost for graded quarrystone is about 90 percent of that of uniform quarrystone, then the graded cost is about 85 percent of the cost of uniform quarrystone. But the layer thickness requirements are about 4.2/3.7 or 14 percent greater.

A further consideration is to evaluate the required crest elevation that will prevent overtopping by the design wave. Instead of going through the analysis for determining wave runup, reference is made to CETN III-2.

The wave runup R/H_o' on graded slopes is approximately 60 percent greater than the uniform quarrystone. Assume runup on the uniform stone slope is elevation 8.0 (3.5 + 4.5) then the runup on the graded stone slope will be to elevation 10.7 (3.5 + 7.2) or about a 33 percent increase in elevation. The table below presents a summation of the various factors.

	Quarrystone	
Factors	Uniform	Graded
Quarry	1.00	0.80
Placement	1.00	0.90
Volume (1)	1.00	1.14
Volume (2)	1.00	1.33
Total	4.00	4.17
Ratio	1.00	1.00

This is approximately a 4 percent increase in cost of armor. Other factors that will increase this even further involve the additional volume of material in the underlayer due to the higher crest elevation. For waves higher than 5 ft (1.5 m), it is usually more economical to use uniform-size armor units.

REFERENCES:

Headquarters, Department of the Army. 1971 (May). "Additional Guidance for Riprap Channel Protection," Engineer Technical Letter 1110-2-120, Office of the Chief of Engineers, Washington, D.C.

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